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Effect of *Tithonia diversifolia* on Compost Pile Heat Built-Up and Physico-Chemical Quality Parameters of *Chimato* Compost

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Abstract

The study objective was to identify blending ratio of *T. diversifolia* and maize stalks that optimizes compost pile's heat built-up, precursor to compost maturity. In this study, 0%, 20%, 40%, 50%, 60%, 80% and 100% *of T. diversifolia* biomass were blended with maize stalks, and then composted using *chimato* composting technology. Temperatures were measured to determine heat built-up. TKN, nitrate-N and C/N ratios were determined using standard methods. Results showed high and more prolonged peak temperatures in compost piles with *T. diversifolia* content of 0%, 20% and 40% implying occurrence of more prolonged decomposition that generated prolonged heat. Resultant composts contained large amounts of non-compost materials (> 37%) and less dark colour indicating high level of immaturity. High but less prolonged peak temperatures were observed in compost piles with 50% and 60% *T. diversifolia* suggesting shortened active and rapid microbial activities that generated less heat. Their composts were very dark in colour and yielded least amounts of non-compost materials (< 17%) which indicated high level of maturity. Significantly large quantities of TKN and nitrate-N and low values of C/N ratios were obtained in chimato composts whose compost piles registered high but less prolonged peak temperatures. Optimal blending composition of 50% and 60% of *T. diversifolia* to maize stalks are judged to have significantly improved moisture content and porosity of feedstock which intensified and shortened active microbial activities leading to generation of optimal heat in chimato compost piles as well as retain optimal TKN, nitrate-N and C/N ratios in resultant composts.

Keywords: *T. diversifolia*, heat built-up, peak temperatures, maize stalks, chimato composts

1. Introduction

The need to apply well decomposed and nitrogen rich composts to improve soil fertility has recently received much attention as a comeback soil management technology (Nalivata, 2007) and as a mitigatory strategy to environmental challenges and concerns such as eutrophication that occur through run-off of chemical/inorganic fertilizers. High quality composts provide a good life cycle solution to poor soils, maintains soil nutrient and provides soil-building benefits that addresses environmental concerns of inorganic fertilizers management. High quality composts are well decomposed and are rich in nitrogen. However, quality of compost is a function of type and quality of vegetative organic resource materials (SAEM, 2008; Gachengo et al., 1999; Sanchez & Demchak, 2009). Quality ingredients determines the extent of microbial activity that break down chemical bonds of compounds thereby transforming chemical energy contained in the bonds to heat, which raises the temperature of the compost pile (WSU, 2010; Biddlestone & Gray, 1987). In turn, temperature ensures availability of microorganisms that work at different temperatures in the compost pile that multiply and change at a rapid rate, and generate heat that adds to heating up process thereby initiating a self-accelerated process (Agromisa, 1990). However, too high temperatures deactivate mesophilic microbes whereas a longer duration of high temperatures accelerates nitrogen loss as ammonia through volatilization (WSU, 2010; WERL, 2005). Temperatures higher than 70 ºC, however, deactivate even most of the thermophilic bacteria (Tsutsuki, 2009).

Traditionally chimato composts are made using maize stalks and grass, which are poor organic resource materials (C/N ratio >60) (Agromisa, 1990; WERL, 2005). However, maize stalks are less bulky and their compost piles possess enormous spaces -high porosity- thereby providing adequate air circulation to the pile structure. Most organic resource materials available for *chimato* composting including maize stalks do not meet the recommended C/N ratios and porosity such that it is mandatory that different organic resource materials be

blended in attempt to obtain optimum C/N ratios and porosity. Blending of more porous and low quality carbon rich and less porous and high quality nitrogen rich would ensure that composting temperatures are optimum for active and rapid microbial activities. This research proposes blending *T. diversifolia* (high quality organic resource materials (Olabode et al., 2007; Jama et al., 2000) with maize stalks (poor quality organic resources (Lewis, 2008; Agromisa, 1990; Biddlestone & Gray, 1987)) to identify blending composition of *T. diversifolia* and maize stalks that optimizes compost pile's heat built-up and temperature progression.

2. Materials and Methods

2.1 Study Site

The study was carried out at the Natural Resource College (NRC) farm in Lilongwe District. NRC lies on 13º 85' S 33º 38' E, at an altitude of 1146 m above sea level, experiences a mean annual temperature of 20 ºC, a mean annual relative humidity of 68% and receives an annual mean rainfall of 892 mm of which 85% falls between November and March (DARETS, 2002).

2.2 Chimato Composting Experiments

Seven *chimato* composting experiments Td0, Td20, Td40, Td50, Td60, Td80 and Td100 in which 0%, 20%, 40%, 50%, 60%, 80%, and 100% of chopped tender *T. diversifolia* were blended with chopped dry maize stalks respectively. *T. diversifolia* plant materials and maize stalks were cut into pieces ranging from 5.0 cm to 10.0 cm. The small sizes were chosen to increase surface area of the organic resource materials and enhance efficient diffusion of air throughout the entire pile for microorganisms to efficiently decompose the organic resource materials (Nalivata, 2007; Michel et al., 2010). Composting experiments were carried out between December and March under iron sheet roofed shade to prevent leaching of water-soluble nutrients especially nitrates.

2.3 Determination of Effect of T. diversifolia on Heat Built-Up

All treatments were closely monitored to make sure that they are exposed to the same conditions. Temperatures readings were taken from all the treatments of *chimato* composts on a daily basis at 12:30 pm for the first ten days. The tenth day was an approximate time for temperatures stabilizing in the mesophilic phase (Tani, 2009). Thereafter, decomposition proceeded without taking temperature readings

2.4 Determination of Effect of T. diversifolia on Physical Characteristics of the Chimato Compost

Intensities of colours of all *chimato* composts were compared to determine which *chimato* compost was more darkish than the other was. To affirm results from colour comparison, chemical colour tests were also carried out by dissolving a 10 g sample of chimato composts in 0.5 M of NaOH and then compare the intensity of the colour that developed (Swift et al., 1979). The colour intensity of the solution showed how well humified organic matter was. Manure and non-manure components of *chimato* compost were determined by crushing the *chimato* compost and then passed through a ½-inch manure screen (Darlington, 2010) and manure materials were expected to pass through the screen. Quantity of each component (manure and non-manure) was measured using digital mass balance.

2.5 Determination of Nitrate-N in Chimato Compost Samples

Standard chimato compost sample solutions were prepared using standard methods. The prepared samples were then analyzed for available nitrogen (nitrate) using a Jenway model No.: 6405 digital UV- Visible Spectro-photometer at wavelength of 410 nm. The values were read out and reported in mg/L in Figure 2.

2.6 Determination of Compost Component and Non-Compost Component

Chimato compost samples were weighed using digital mass balance, homogeneously mixed and crushed to produce representative sample. Compost components and non-compost components were determined by passing the crushed composts through a ½-inch manure screen (Darlington, 2010). The results were reported in Figure 3.

2.7 Determination of TKN and Organic Carbon

The fine *Chimato* compost samples were tested for TKN and total carbon using the Kjeldahl apparatus (Jeffery et al., 1989). The resulted were reported in Table 1.

2.8 Determination of C/N Ratio of Product Chimato Compost

C/N ratio of each type of product chimato compost was estimated by dividing chimato compost's total carbon by TKN (WSU, 2010) as follows:

$$C / N = \frac{\text{Total \% Carbon}}{\text{Total \% Nitrogen}} \quad (1)$$

2.9 Data Analyses

The collected data were subjected to analyses of variance (ANOVA), to compare treatment effects on total-N and nitrate-N. Treatment differences were evaluated using the least significance difference (LSD) at $P< 0.05$.

3. Results and Discussion

3.1 Effect of T. diversifolia Content on Heat Built Up

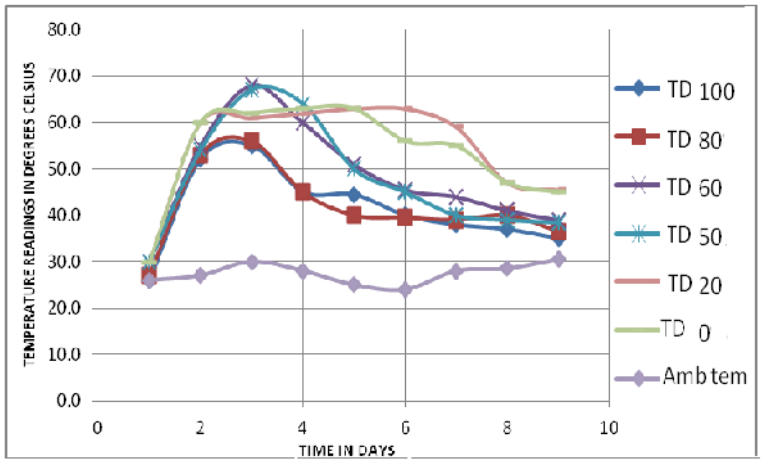

Figure 1. Effect of amount of T. diversifolia on Heat built up of compost product piles

Temperature of Td80 and Td100 rapidly increased to high thermophilic peak temperature (54.5 and 55 ºC respectively) then rapidly dropped to mesophilic phase, with Td100 reaching its peak temperature first followed by Td80. Prolonged high thermophilic temperatures were observed in chimato composts Td0, Td20 and Td40 that rose to peak temperatures (64, 65 and 70 ºC respectively) before dropping to lower mesophilic temperatures. The prolonged temperatures indicate that quantity of heat built-up in Td0, Td20 and Td40 was larger than in Td80 and Td100. Peak temperatures of Td0, Td20 and Td40 were significantly different from those of Td80 and Td100.

The significant differences are attributed to quantity of *T. diversifolia* used to make these chimato compost piles which significantly affected porosity, initial C/N ratio and microbial activities (Biddlestone, 1987; WSU, 2009) in chimato compost piles that also affected substrate digestibility. The blending composition probably provided the organic resources of Td0, Td20 and Td40 with large initial C/N ratio (67:1, 41:1, 37:1) and organic resources of Td80 and Td100 with lower initial C/N ratio (15:1, 10:1) such that Td0, Td20 and Td40 organic resources possessed large quantities of carbon atoms without corresponding provision of nitrogen atoms for microbes to use as source of energy and as building materials of their structures respectively. As such, microorganisms slowly digested the abundant carbon atoms in the organic resource by using and/or reusing their stored limited nitrogen to burn large quantities of carbon atoms for a longer period supporting findings by Petrus et al. (2009) and Tani (2009) that slow and passive microbial activities are experienced in compost piles with initial C/N ratio of greater than 30:1. Thus, the process prolonged exothermic decomposition reaction that induced the observed high-prolonged temperatures (heat built-up) as well as broad and greater range of compost heat built-up in chimato composts Td0, Td20 and Td40.

The observed rapid increase in temperature in Td80 and Td100 could possibly be attributed to rapid and active initial mesophilic microbial activities (WSU, 2009; ICRAF, 1998) that enhanced fastest though short-lived exothermic decomposition reaction leading to rapid heat built-up in the chimato compost piles. Blending that included 100% and 80% of *T. diversifolia* (in Td80 and Td100) lowered initial C/N ratios of the compost piles to fall below the recommended range of 20-30:1 or lower (Petrus et al., 2009; Tani, 2009). Thus, Td100 and Td80 possibly provided microorganisms with enormous amounts of nitrogen, easy to digest substrate, for building their cell structure during microbial activities. Since rapid and active microbial activities are experienced in compost piles with initial C/N ratio of lower than 30:1 because they possess large quantities of easy to digest substrate as stated above microorganism digested and decomposed the organic resource materials of Td100 and Td80 rapidly, leading to fast generation of heat. However, it was observed that temperatures in Td100 and Td80 rapidly dropped to lower mesophilic temperatures. This could possibly be associated with slowing down of

growth and respiration of microorganisms activities after the limited quantities of carbon atoms were digested (Petrus et al., 2009; Tani, 2009) and used up, which further limited exothermic reaction process of decomposition (Biddlestone, 1987; WSU, 2010). This limitation probably led to limited generation of heat, hence the observed low temperatures. Thus, decomposition processes in Td100 and Td80 occurred rapidly and heat built-up short lived in the thermophilic phase due to limited supply of carbon even though nitrogen was in abundance.

The observed prolonged broad and greater range of thermophilic temperatures in chimato compost piles Td0, Td20 and Td40 are attributable to their high initial C/N ratios (C/N ratio 66:1, 41:1 and 37:1 respectively; C/N> 31:1) of the blend that induced slow microbial decomposition process because their substrate possessed abundant carbon in agreement to reports by WSU (2010), Petrus et al. (2009) and Tani (2009). It is suggested that maize stalks provided the large quantities of high carbon content cellulosic materials (lignin) whose oxidation and digestion generate large amounts of heat that made Td0, Td20 and Td40 to experience prolonged high temperatures. Since high prolonged heat built-up are symptomatic of loss of nitrogen and immaturity compost, chimato composts Td0, Td20 and Td40 could probably yield less nitrogen and show physical appearances of immaturity as discussed in subsequent sections.

3.2 Effect of 50% and 60% T. diversifolia Content on Heat Built Up

High peak temperatures of *chimato* compost piles of Td50 (67 ºC) were not significantly different from Td60 (66 ºC) ($p= 0.201$; $\alpha= 0.05$). The temperatures were less prolonged moderately progressed without over heating the chimato composts piles. The observations suggest that blending *of T. diversifolia* and maize stalks in chimato compost piles Td50 and Td60 seemed to have provided a balanced proportion of carbon atoms - adequate amount of energy source- and nitrogen atoms - adequate amount of cell building materials. Microorganism efficiently used carbon atoms in converting available nitrogen into protein to building their cell structure. The moderate short stay of built-up heat in *chimato* compost piles Td50 and Td60 is attributable to absence of hard to digest materials such lignin, cellulose, and poly-phenols, which required thermophilic microbes' action as already discussed. Based on temperature progression, optimum-blending ratios probably occurred in chimato compost with *T. diversifolia* content of 50% and 60% that enhanced optimum (rapid and active) microbial activities that generated optimum heat for sustainable decomposition process. Thus, optimum microbial activities induced heat built-up that was neither too low nor too high; induced heat that neither dropped too soon nor prolonged for longer period for microbes to enhance sustainable decomposition process.

3.3 Effect of Heat Built up on TKN, Nitrate-N, C/N Ratio

Table 1. Effect of chimato compost pile heat built-up on mean TKN, Nitrate-N & C/N ratio

Chimato Compost Treatment	Mean TKN %	Std. error	Mean Nitrate-N %	Std error	Estimated initial C/N Ratio	Mean Final C/N Ratio of resultant compost	Std error
Td0	1.17	±0.13	0.078	±0.002	66:1	38:1	±2
Td20	1.37	±0.08	0.23	±0.02	41:1	27:1	±2
Td40	1.67	±0.13	0.80	±0.01	28:1	18:1	±1
Td50	2.33	±0.10	1.04	±0.03	24:1	13:1	±1
Td60	2.47	±0.10	0.98	±0.02	20:1	10:1	±1
Td80	2.02	±0.26	0.57	±0.01	13:1	14:1	±1
Td100	2.06	±0.21	0.70	±0.02	10:1	11:1	±1

As shown in Table 1, *chimato* composts analysis showed that Td0, Td20 and Td40 whose heat built-up were significantly prolonged possessed low TKN, low Nitrate-N and large final C:N ratios whereas Td50, Td60, Td80 and Td100 whose heat built-up was short-lived possessed high TKN, high Nitrate-N and small C:N ratios. This revelation suggests that composts piles of Td0, Td20 and Td40 were heated for a long time while those of Td50, Td60, Td80 and Td100 were not sufficiently heated of which both affected TKN, Nitrate-N and C/N ratios negatively. Ingredients of Td0, Td20 and Td40 piles possessed low initial nitrogen (high C/N ratio), optimum aeration and low moisture content. Therefore, microbial activity probably prolonged because there was insufficient amounts of nitrogen for microbes to use in digesting the feedstock with speed. As such, microbes

reused the insufficient nitrogen to build up their structures (Agromisa, 1990; Ngeze, 1993; SAEM, 2008; WERL, 2005) in digesting the ingredients which prolonged the digestion process to take a little longer as observed. In addition, since significant nitrogen losses are certain to occur in such high temperatures prolonged microbial activities due to ammonia volatilization, it resulted in significant TKN and nitrate-N losses hence the low observed TKN and nitrate-N.

Ingredients of Td50, Td60, Td80 and Td100 piles possessed high initial nitrogen (low C/N ratio), poor aeration and high moisture content. Microbial activity was short-lived in Td50, Td60, Td80 and Td100 piles because microbes had probably plenty nitrogen atoms to use to digest available little carbon atoms, which was accomplished with greater speed and significantly short-lived heat built-up of compost piles. However, Td80 and Td100 piles experienced poor aeration and poor moisture content, since the green secreted additional which made Td80 and Td100 piles more wet than Td50 and Td60 piles. This wet and poor porosity condition probably nitrogen in piles of Td80 and Td100 to enhance faster aerobic decomposition which probably lead to Nitrates formation that characterizes anaerobic decomposition. Nitrates were leached out of the compost piles as leachate or as slurry (Manahan, 2008) that collected under the piles. Hence, the short-lived heat built-up in Td80 and Td100 is associated to decreased recorded amounts of TKN and nitrate-N while the less prolonged were recorded in Td80 and Td100 while high amounts were recorded in. Td50 and Td60 did not experience prolonged heat built-up that forced microbes to reuse the available nitrogen to build up their structures thereby causing significant nitrogen losses nor did they experience short-lived heat built-up which was wet and induced favorable conditions for anaerobic decomposition and significant nitrates losses. As a result, microbes made full use of available carbon atoms to get rid of excess nitrogen as ammonia (Petrus et al., 2009; Onwueme & Sinha, 1991). Since ammonia volatilization is certain to occur in compost piles with high nitrogen content, Td80 and Td100 were certain to experience to reductions of both TKN and nitrate-N. Therefore, it can be concluded that, optimum porosity and optimum amounts of initial nitrogen and carbon atoms occurred in Td50 and Td60 induced active and rapid aerobic decomposition that determined the optimum heat built-up.

3.4 Effect of T. diversifolia Percentage on Physical Appearance of Chimato Compost

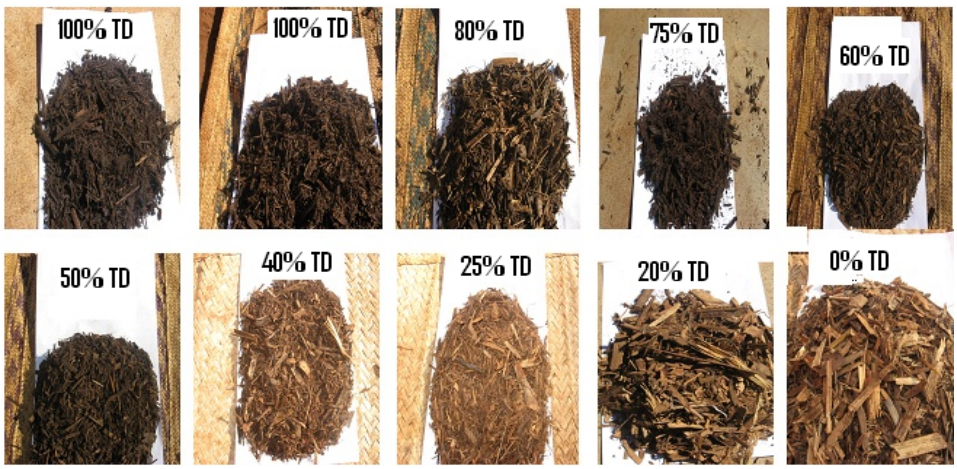

Figure 2. Effect of amount of *T. diversifolia* and heat built up on appearance of compost product after 50 days

As shown in Figure 2, colour intensities of *chimato* composts Td0, Td20, Td40, Td50 Td60 and Td100 were observed increasing in that order with Td0 being least dark whereas Td60 and Td100 were most dark in colour. Even though colour intensity of Td50 was less dark than that of Td60. they were not significantly different from each other. Colour intensity of Td100 was not significantly different from that of Td60. Generally, colour intensities of the *chimato* composts were observed increasing in increasing order of quantities of *T. diversifolia* in the compost piles (up to 60% of *T. diversifolia* in blending composition). Beyond 60% of *T. diversifolia*, other variables seem to have taken a leading influence on decomposition process and on intensity of colour of compost product. Most dark colours in composts indicate high level of maturity and how well-finished the composting processes (SAEM, 2008; Swift et al., 1979; WERL, 2005). Therefore, the results indicate that *chimato* composts Td50, Td60 and Td100 were probably well finished and more matured while Td0, Td20 and Td40 were immature with poorly finished composting process. The results indicated occurrence of minimal decomposition

likely to yield least amounts of compost. *Chimato* compost Td80 was less dark than Td60. Thus, besides being made up of higher percentages of *T. diversifolia* content, *chimato* compost Td80 was observed lighter (less dark) in colour than the preceding ones. The observation could be attributable to high level of water content of secreted by leafy *T. diversifolia* (the greens) that characterized their *chimato* compost piles that reduced amount of air spaces in the pile. The porosity reduction rendered microbes with insufficient amounts of oxygen that probably induced anaerobic respiration (rotting) that made the ingredients to rot rather than decompose (ICP, 2004; Michel, et al, 2010; SAEM, 2008; WERL, 2005), hence the *chimato* compost made using *T. diversifolia* content of 80%, was less mature and less dark than the preceding ones.

3.5 Colour Test Results of Chimato Compost Products

When 10.0 g of *chimato* compost were dissolved in 0.5 M of NaOH, study results showed that chimato compost Td50 and Td60 formed most blackish solutions comparable to *chimato* compost Td100. *Chimato* compost Td0, the control, formed a solution with a colour interpreted too light to be a compost (Johnson, 2007; Swift et al., 1979). The intensity of the colour was most dark in *chimato* compost Td100 (with lowest percentages of *T. diversifolia*) followed by Td60 and Td50 then Td80, Td40, Td20 descending in that order down to *chimato* compost Td0 with lowest percentages of *T. diversifolia*. This observation also confirms the possibility of formation of larger amounts of humus in chimato compost made using larger proportion of *T. diversifolia* than those made using lower percentages of *T. diversifolia*. Since humus as well as composts turn black in a solution of NaOH and high intensity of black colour indicates high levels of humus and composts, the most dark colour observed in Td50, Td60, Td80, and Td100 suggests that these composts were either well-humified organic matter (more humus) or well composted (Swift et al., 1979). However, humus is a product of anaerobic respiration (rotting) while compost is a product of aerobic respiration (decomposition) (Michel, et al., 2010). The dark brown colours in chimato compost made using T. diversifolia content of larger than 80% could be due to humus since these chimato compost piles were too wet indicating high moisture content that probably characterized them with anaerobic respiration. *Chimato* compost made using 0% *T. diversifolia* content produced very light in colour compost that indicated occurrence of minimal decomposition likely to yield least amounts of compost.

3.6 Amount of Compost and Non-Compost Components of the Chimato Compost

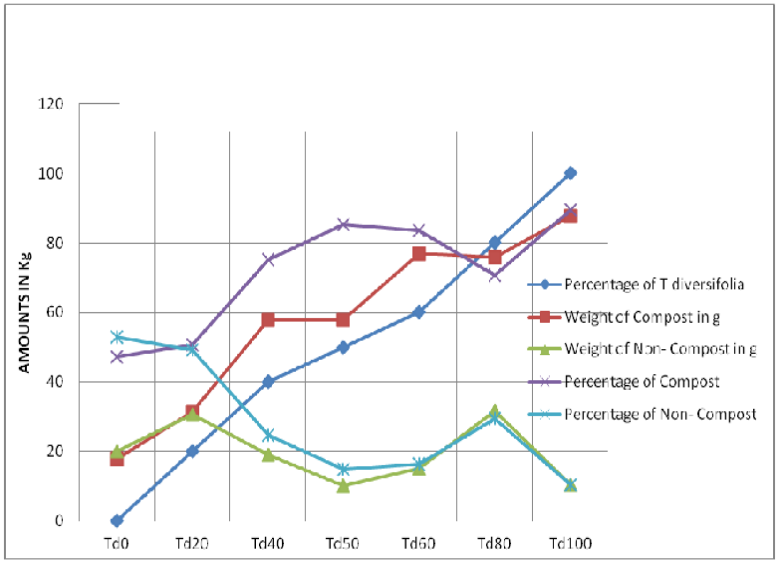

Figure 3. Effect of *T. diversifolia* on amount of compost components and non-compost components

Generally, quantity of non-compost components increased in chimato compost with increase of quantity of *T. diversifolia* used in making chimato compost piles. As shown in Figure 3, *chimato* compost Td100 yielded least quantity of non-compost components whereas Td0 yielded greatest quantity of non-compost components.

The non-compost components in *chimato* compost increased in the following order of *T. diversifolia* content: 100% = 50% < 60% < 40% < 80% < 20% < 0%. Most of ingredients in *chimato* compost piles made using *T. diversifolia* of 100% contained greater proportion of easily degradable materials and minimal amounts of hard to

decompose substances such that they were completely decomposed by the 40th day. Ingredients consisting of greater composition of nitrogen rich ingredients (which are low in lignin and phenol content and possess soft leaves), such as *T. diversifolia* have high level of degradability (SAEM, 2008; WERL, 2005; ICRAF, 2008; Biddlestone & Gray, 1987). *Chimato* compost Td50 then Td0, Td20 and Td40 (being made of greater percentage of maize stalks) possessed large proportions of difficult to degrade ingredients that limited degradability of the composite ingredients. This limitation resulted in prolonged, slow, and less active microbial activities, which yielded more non-compost (non-manure) components. Even though *T. diversifolia* content was lower in chimato composts Td50 and Td60 than in chimato composts Td80 and Td100, comparable percentage of compost and non-compost components were found suggesting that both attained greater degradability.

Greater degradability in *chimato* compost Td50 and Td60 could also be attributable to balanced provision of nitrogen and carbon that microbes used to build up their cell structure and as energy source respectively (WERL, 2005) that in turn provided greater microbial activities for active and rapid sustainable decomposition process (SAEM, 2008; Biddlestone & Gray, 1987). As previously discussed, greater degradability could also be attributable to availability of sufficient air spaces by the less bulky maize stalks (50% and 40% of maize stalks). This probably enhanced aerobic respiration that supported sustainable active and rapid composting process as well (SAEM, 2008; Biddlestone & Gray, 1987; Lewis et al., 2008; *WSU*, 2010). This is in agreement to the heat built-up trend already discussed which supports formation of well-finished compost.

4. Conclusion

The results have shown that blending ratios of 50% and 60% of *T. diversifolia* biomass with maize stalks were optimum and enhanced rapid and active microbial activities that generated optimum heat for sustainable decomposition process. The resultant composts were more matured and possessed large quantities of nitrate-N and TKN and their C/N ratios were within the recommended ranges of mature composts. Smallholder farmers should be encouraged to compost *T. diversifolia* blended with maize stalks using these blending ratios in order to utilize large amounts of nitrogen contained in *T. diversifolia*. Farmers will find application of composts made from *T. diversifolia* more rewarding than application of raw *T. diversifolia* due to reduction of bulk mass that significantly reduces number of trips carried to the field and the associated cost of transportation.

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